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INTERACTION OF ELECTROMAGNETIC WAVES AND
ELECTRON BEAMS IN SYSTEMS WITH CENTRIFUGAL-
-ELECTROSTATIC FOCUSING (GMP)

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Representation of electron beams in the form of electronic waveguides opens new possibilities in construction of a general theory for the wide class of electron-beam devices of super-high frequencies, such as traveling-wave tubes, backward-wave tubes, electron-wave amplifiers and other systems. This generalization in a number of cases, enables to provide a thorough analysis for the phenomena that occur in such systems. However, it is natural, that radio-frequency properties of either electronic waveguide (electron beam) will be determined, first of all, by its configuration and by the character of electron motion in this waveguide i.e. it will depend to a great extent upon the method of electron beam shaping and focusing. Here in we will endeavour to show a number of radio-frequency properties which are acquired by the electron beam when focused by the centrifugal-electrostatic method.

Let us begin with the linear spirotron consideration. Similar to the usual traveling-wave or backward-wave tubes the spirotron consists of metallic waveguiding structure and electron waveguide interconnected electro-dynamically at some section and loaded with reactances at the ends (see fig.1).

A scheme of a typical linear spirotron is illustrated in fig. 2. The waveguiding slow-wave structure in a linear spirotron, similar to that adopted in the usual types of traveling-wave tube, is represented either by the helix or

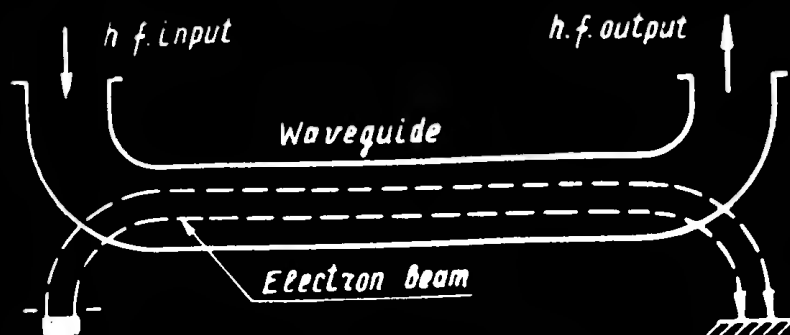


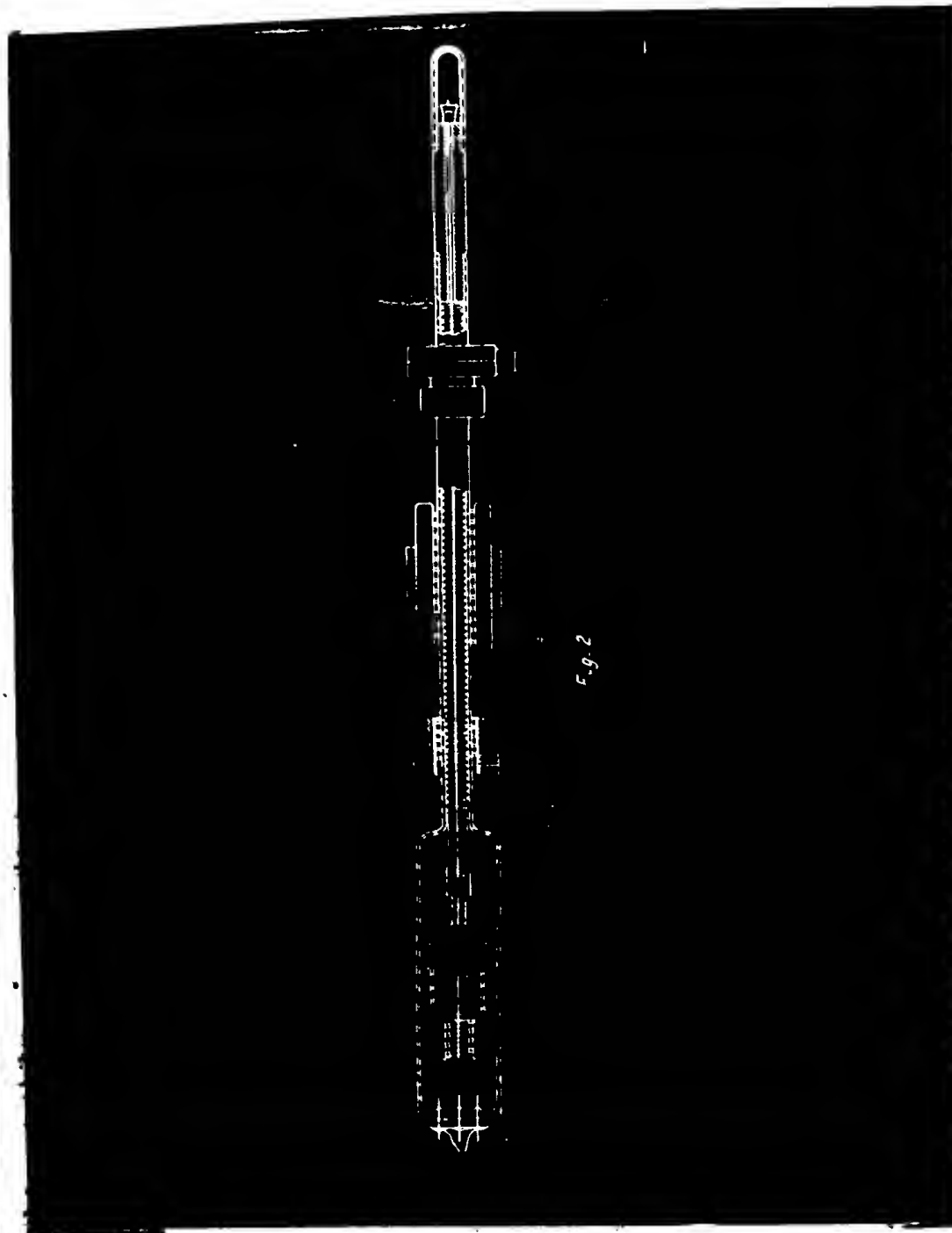
Fig. 1

any other axial symmetrical structure, which is complicated to a certain extent by a focusing electrode. As far as the electron waveguide is concerned, it is a tubular beam with helix-type motion of electrons. It is known that the use of tubular beams discloses a number of possibilities to obtain valuable radio-frequency characteristics in devices of the traveling-wave type. Let us now consider the extent to which these properties are present in the system with centrifugal electrostatic focusing. The theoretical analysis of amplification of the traveling-wave tube (TWT) shows that when a helix slow-wave structure is filled with tubular beam there appears the possibility of system bandwidth increasing. This is well illustrated in a diagram (see fig.3) which was given in a paper by Pearce. On the vertical axis of this diagram the value of the gain per unit length is plotted, while along the horizontal axis the value of βa is shown (where $\beta = \frac{a}{v_{ph}}$ and a - radius of helix).

It may be seen from the diagram, that at filling the helix with the beam $\frac{\gamma_{beam}}{\gamma_{helix}} = 0.7 - 0.75$, in case of tubular beam, the impedance changes slightly at the increase of the frequency, while in case of continuous beam the wave impedance decreases sharply.

The large band width of spirotron beam interaction with the helix delaying structure has been experimentally verified.

At the amplification exceeding over 20 db with drops of the order of 5 db., a band width with the relation of



bandlimiting frequencies of the order 1:3 has been obtained on a linear spirotron (see fig.2) with two coupled helix transducers used as matching devices. It should be pointed out that the limitation of the band width was due to certain dispersion of the helix-globe system. At a small adjustment of the beam velocity, the bandwidth was found to be 1:4.5.

Since the electrons in a tubular beam, as compared to those in pencil beam, move in the region of the more homogeneous radio-frequency field, they may be guided close to the slow-wave structure so that the effectiveness of interaction between the beam and the delayed wave (i.e. electronic efficiency) may be increased. This property of the spirotron beam is of great significance, especially at small beam currents, when the efficiency of an ordinary traveling-wave tube (TWT) considerably decreases. Thus, for instance, the output of linear mean power spirotron was found to be at the wavelength 12-20 cm and a current equal 25 ma, from 10 to 12.5 watts at the electron efficiency of 25 to 30 percent. At the reduction of wave-length up to $\lambda = 8-10$ cm a sharp decrease of beam current to 6 ma the efficiency remained still high, being of the order of 23 per cent. Finally, the efficiency of 12 per cent was obtained at the current of only 0.8 ma.

It should be mentioned, that a particular property of spirotron beam, as it seems to us, helps to obtain a high efficiency value. The point is, that in the tubular beam focused by means of the centrifugal electrostatic method, in forming electron bunches under the action of high-frequency field, a great concentration may be obtained in the axial

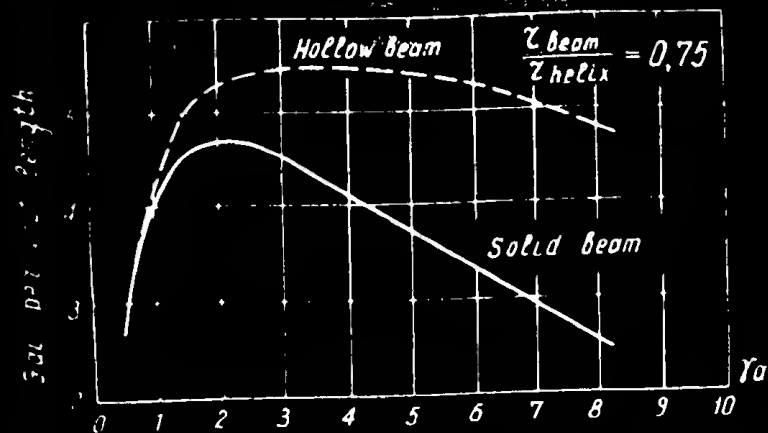


Fig. 3

direction on account of defocusing in the radial direction. As far as the limitations of efficiency are concerned due to the destroying of electron bunches which can not expand in the radial direction, it should be mentioned that this effect has been convincingly disclosed in the known paper by Catler.

The high-frequency output of the system is determined not only by the electronic efficiency, but also by the direct current energy transferred by the electron beam. In this respect for the electronic waveguide, as well as, for electromagnetic one, we may speak of the maximum transmitting capacity of the waveguide concerned.

The direct current output of a beam or an electronic waveguide is determined by the accelerating voltage and current. In an ordinary focusing system with a longitudinal magnetic field, the current and the voltage of the beam are depending one from the other. And, as it is known, there exists a maximum value of current, which can be passed through the drift tube $I = 32.4 \cdot 10^{-6} U_e^{3/2}$.

Therefore to increase the power of traveling-wave tubes it becomes necessary to increase the phase velocity although sometimes this is not desirable.

In the system CEP, the current may be increased without the necessity to change the axial velocity of electrons and hence the wave phase velocity does not change. This is accomplished by the increase of the focusing voltage value and the transition to fast rotating beams. The maximum current in the CEP system $I = 33 \cdot 10^{-6} \frac{U_{roc} \bar{U}_e}{C}$ where U_{roc} - voltage between cylinders (in volts), U_e - axial velocity of electrons in waves (in volts), C - conductivity of system depending

on the system geometry.

The possibility of flexible parameter control of an electron waveguide employed in CWP system must be also considered.

Thus, for instance on the basis of spirotron, the backward - wave tube for a 10 cm range with tubular beam and double helix slow-wave system was realised.

The slow-wave system provides a continuous electronic retuning of 20 to 30 per cent by a single voltage change and a bandwidth 1:2 by two voltage changes. The output power of this tube is of the order of several tens mW^{x)}. Here, as it seems to us the principle of electronic retuning and electrostatic focusing were successfully combined, while the same results in case of periodic electrostatic focusing present mean while considerable difficulties.

In the foregoing pages we considered the electron beam as a part of the electron waveguide with matched loads at the ends. Yet, if the output of such an electron waveguide will be connected with its input, then this electron waveguide will be transformed to an electron resonator. The beam in such a system after the first interaction with the high frequency field of the structure, is again introduced into the interaction region, where it completes n cycles. If there are several wave lengths along the length of the electron resonator, it means that we are dealing with a traveling-wave resonator.

The more consecutive results of this work done in IRE by L.A. Kernashevsky and T.A. Novskova will soon be published

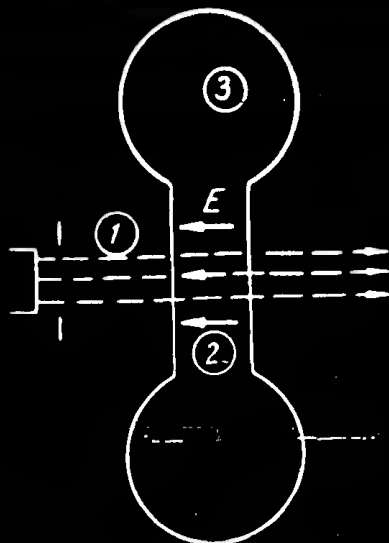


Fig 4

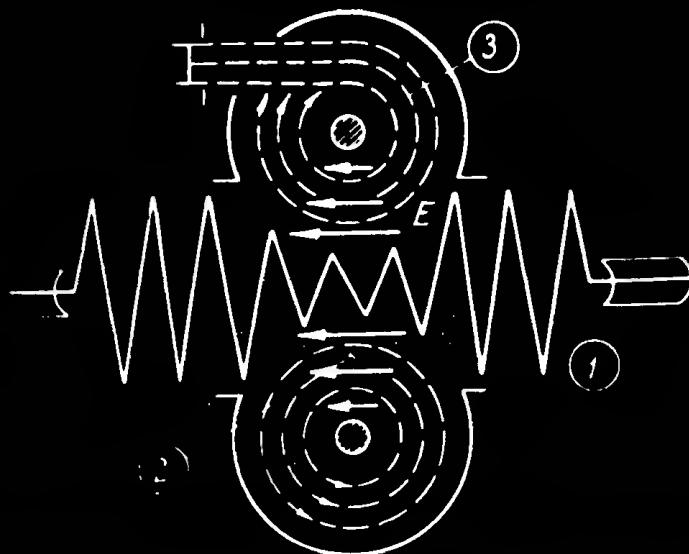


Fig 5

On the other hand, there may be electron resonators similar to cavity resonators. In order to provide the dependence of the frequency properties of a system just by the very electron resonator, the latter should be loaded by the waveguiding structure without substantial reflections at the ends and moreover the electron resonator should not be coupled with an ordinary resonator. The interaction of an electron resonator with an external circuit may be accomplished on either wave irrespective whether it is a slow-wave or it has the velocity of light.

The possibility of forming in the CEF systems, electron beams of very complicated shape enables to construct various types of electron resonators.

The principal particularities of an electron resonator can be seen at once when the ordinary klystron is compared with the CEF system, which may be called "antiklystron" according to its principle of action.

The scheme of klystron is represented in fig.4. Where:
1 - is the electron beam which is used as a source of energy;
2 - region of the interaction between the radio-frequency field and the beam.
3 - Resonant cavity used for the accumulation of radio-frequency energy. The frequency of generated or amplified oscillations is determined by this cavity.
The scheme of "antiklystron" is represented in fig.5, where:
1 - wave guide structure necessary to form the high-frequency field, which interacts with the electron beam, and to introduce the energy into the system and to yield it out of the system.
2 - region of interaction of the electron resonator with the external structure.
3 - an electron resonator

which is a toroidal electron beam with circular or helix electron trajectories.

When a radio-frequency field is present in the wave-guiding structure, there is a field component E in the region 2 actively interacting with the electrons. Owing to the multiple circulation of the electron beam in the system which is equivalent to the multiple reflections of electromagnetic wave in an ordinary resonator, an accumulation of modulation will take place in a beam and this may be considered as an accumulation of radio-frequency energy in an electron resonator. The frequency of an electron resonator is determined by the electron circulation frequency and may be altered by the change of focusing electrodes potentials. The investigation of systems with electron resonators (CEP) in decimetre wave range has shown that such systems provide amplification and generation of signal with a wide electron retuning of frequency in a band-width about 1:2. Electron resonators possess a quality factor the value of which changes from a hundred to a thousand. In the electron resonator as well in ordinary resonators it was possible to excite overtones.

In conclusion it should be mentioned, that the development and investigation of electrostatic methods of electron beams formation and focusing seems to us exceedingly actual. Electrostatic systems guarantee progress of the existing devices for superhigh frequencies and opens possibilities for developing of new methods of generation and amplification of microwaves.